A few synthesizers and their algorithms

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aLisp

[Andre, Bhaskara, Russell, … 2002]

aLisp: learning with partial programs

Problem:

- implementing AI game opponents (state explosion)
- ML can’t efficiently learn how agent should behave
- programmers take months to implement a decent player

Solution:

- programmer supplies a skeleton of the intelligent agent
- ML fills in the details based on a reward function

Synthesizer:

- hierarchical reinforcement learning

What's in the partial program?

Strategic decisions, for example:

- first train a few peasant
- then, send them to collect resources (wood, gold)
- when enough wood, reassign peasants to build barracks
- when barracks done, train footmen
- better to attack with groups of footmen rather than send a footman to attack as soon as he is trained

[from Bhaskara et al IJCAI 2005]

Fragment from the aLisp program

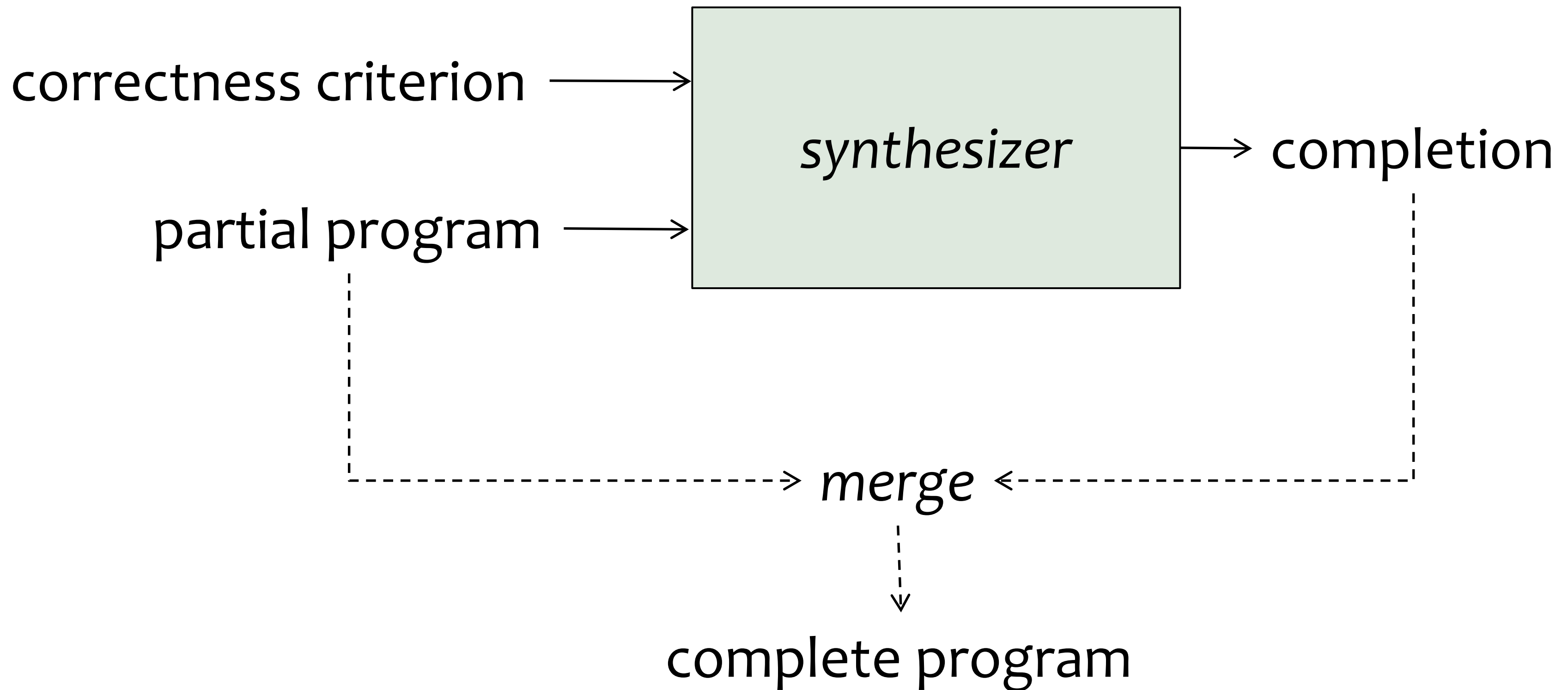
```
(defun single-peasant-top ()
   (loop do
        (choose '((call get-gold) (call get-wood)))))

(defun get-wood ()
   (call nav (choose *forests*))
   (action 'get-wood)
   (call nav *home-base-loc*)
   (action 'dropoff))

(defun nav (l)
   (loop until (at-pos l) do
   (action (choose '(N S E W Rest)))))
```

this.x > l.x then go West

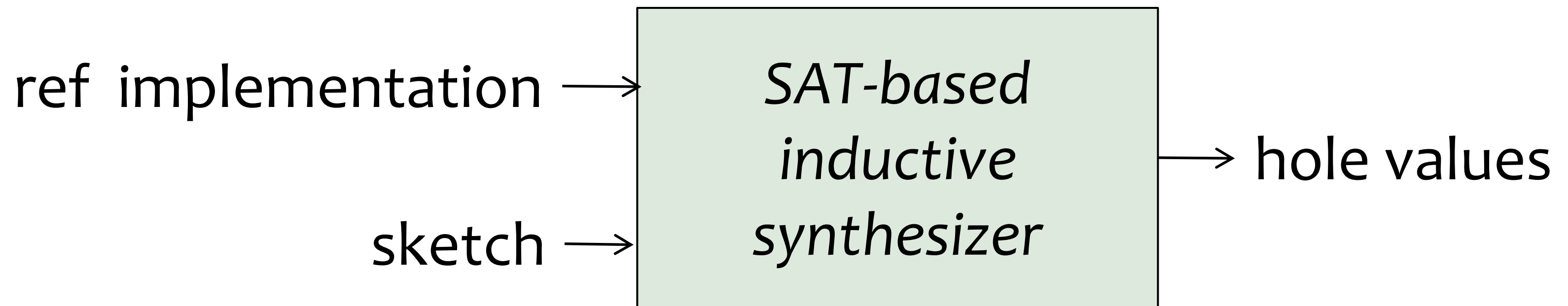
check for conflicts

...

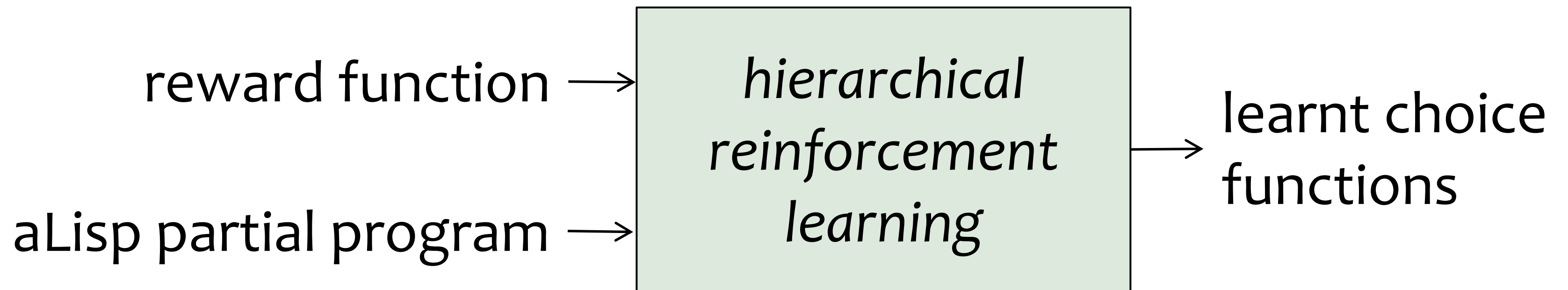
It’s synthesis from partial programs



SKETCH



aLisp



First problem with partial programming

Where does specification of correctness come from?
Can it be developed faster than the program itself?

Unit tests (input,output pairs) sometimes suffice.

Next two projects go in the direction of saying even less.

SMARTedit*

[Lau, Wolfman, Domingos, Weld 2000]

SMARTedit*

Problem:

- creation of editor macros by non-programmers

Solution:

- user demonstrates the steps of the desired macro
- she repeats until the learnt macro is unambiguous
- *unambiguous* = all plausible macros transform the provided input file in the same way

Solver:

- version space algebra

An editing task: EndNote to BibTex

```
%0 Journal Article
%1 4575
%A ^Richard C. Waters
%T The Programmer's Apprentice: A Session with KBEmacs
%J IEEE Trans. Softw. Eng.
%@ 0098-5589
%V 11
%N 11
%P 1296-1320
%D 1985
%R http://dx.doi.org/10.1109/TSE.1985.231880
%I IEEE Press
```

→

```
@article{4575,
    author = {Waters, Richard C.},
    title = {The Programmer's Apprentice: A Session with KBEmacs},
    journal = {IEEE Trans. Softw. Eng.},
    volume = {11}, number = {11}, year = {1985},
    issn = {0098-5589},
    pages = {1296--1320},
    doi = {http://dx.doi.org/10.1109/TSE.1985.231880},
    publisher = {IEEE Press}, address = {Piscataway, NJ, USA},
}
```

Demonstration = sequence of program states:

```
1) cursor in (0,0)    buffer = "%0 …"    clipboard = ""
2) cursor in ^        buffer = "%0 …"    clipboard = ""
3) …
```

Desired macro:

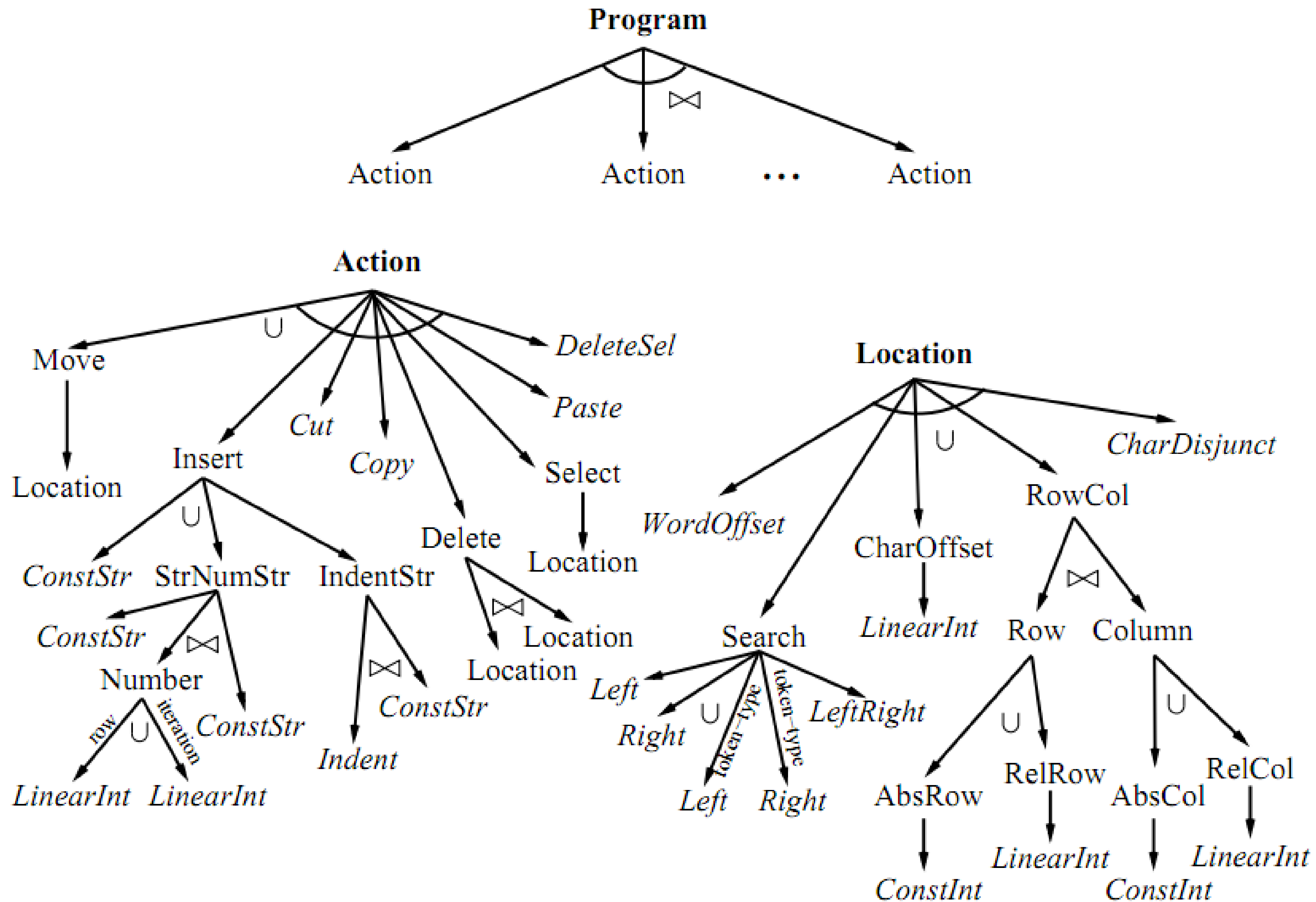
```
move(to after string "%A ")
…
```

Version space = space of candidate macros

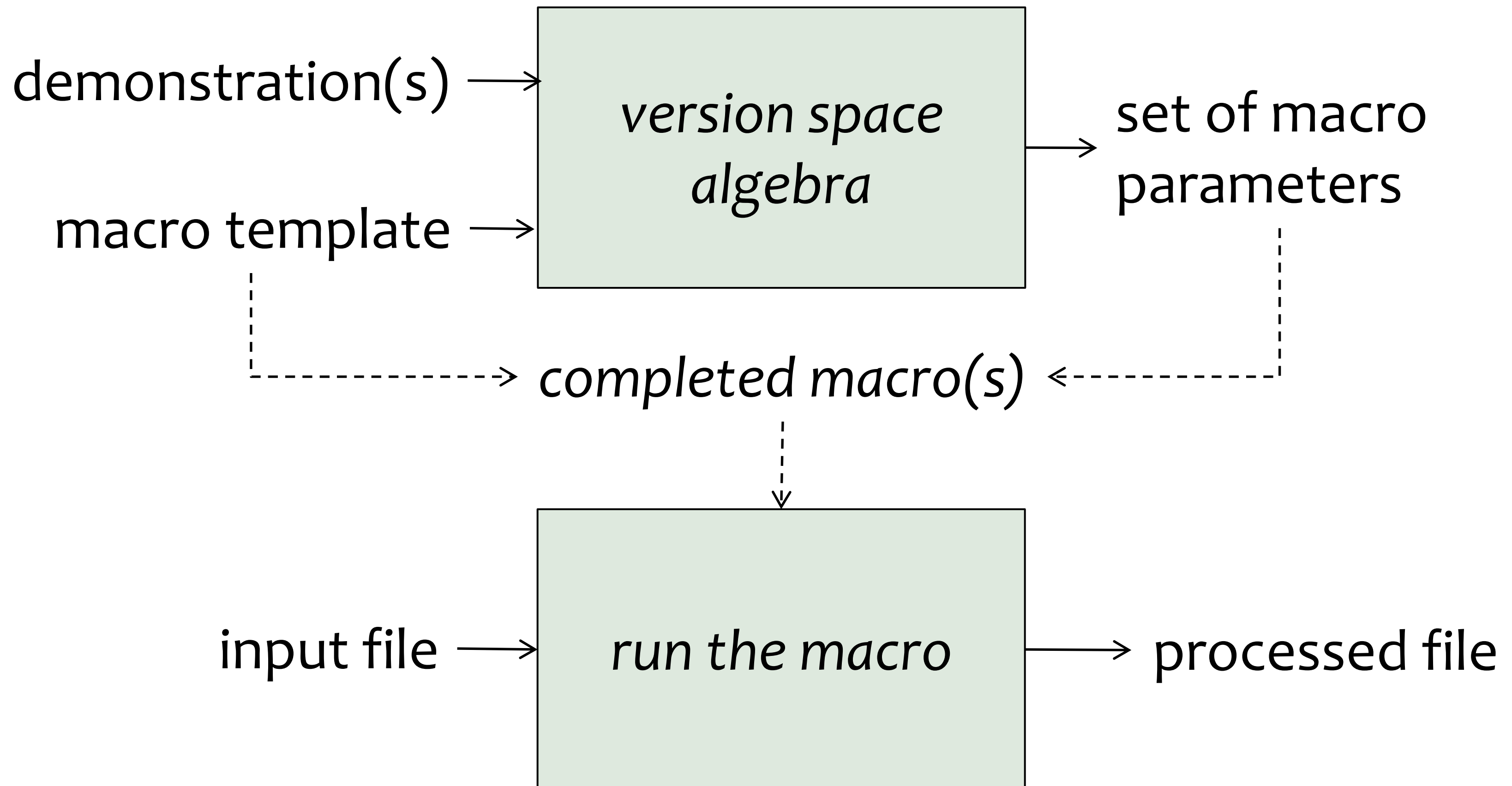
Version space expressed in SKETCH (almost):

```
#define location {| wordOffset(??) | rowCol(??,??)
                   | prefix("??")   |  … |}

repeat ?? times {
  switch(??) {
  0:   move(location)
  1:   insert({| "??" | indent(??,"??") |}))
  2:   cut()
  3:   copy()
       …
  }
}
```

Version Space for SMARTedit



SMARTedit*



Denali

[Joshi, Nelson, Randall PLDI 2002]

synthesis with automated theorem proving

Denali

Problem:

- scalable super-optimizer (previous ones: gen-and-test)

Solution:

- spec: the program, given as an instruction sequence
- process: write down instruction-equivalence axioms; rewrite the spec in all possible ways, using E-graphs; pick fastest one

Solver:

- no solver; new programs obtained by rewriting, as in the Simplify theorem prover (Nelson-Oppen)
- (given a candidate *P*, SAT solver computes *P*'s exec time)

Input

```
\proc byteswap4 : [ a : int ] -> int =
  \var r : int \in
    r := 0 ;
    r<0> := a<3> ;
    r<1> := a<2> ;
    r<2> := a<1> ;
    r<3> := a<0> ;
    \res := r ;
  \end
```

Figure 3: Envisioned program for 4-byte swap. `w<i>` denotes byte `i` of word `w`, that is, `selectb`(w, i). Our current prototype requires a parenthesized input syntax in the style of figure 6.

Output

```
// Register Map: {a=$16, r=$1, \res=$0, 0=$31}
byteswap4:                  #   assume  a = wxyz
  extbl   $16, 1, $2        # 0, U1  ; $2 = 000y
  insbl   $16, 3, $3        # 0, U0  ; $3 = z000
  nop                       # 0
  nop                       # 0

  insbl   $2, 2, $2         # 1, U1  ; $2 = 0y00
  extbl   $16, 3, $4        # 1, U0  ; $4 = 000w
  nop                       # 1
  nop                       # 1

  or      $4, $3, $3        # 2, L0  ; $3 = z00w
  extbl   $16, 1, $4        # 2, U1 (unused)
  extbl   $16, 2, $4        # 2, U0  ; $4 = 000x
  nop                       # 2

  insbl   $4, 1, $4         # 3, U0  ; $4 = 00x0
  or      $2, $3, $2        # 3, L0  ; $2 = zy0w
  nop                       # 3
  nop                       # 3

  or      $4, $2, $0        # 4, U0  ; $0 = zyxw
  ret     ($26)             # 4, L0
  nop                       # 4
  nop                       # 4
.end byteswap4
```

Figure 4: Generated EV6 assembly program for four byte swap. The unused instruction is necessary: if it were a nop, the following extbl instruction would be scheduled on the wrong cluster.

Axioms: equiv of instruction sequences

$$(\forall\, x, y :: \texttt{add64}(x, y) = \texttt{add64}(y, x))$$

$$(\forall\, x, y, z :: \texttt{add64}(x, \texttt{add64}(y, z)) = \texttt{add64}(\texttt{add64}(x, y), z))$$

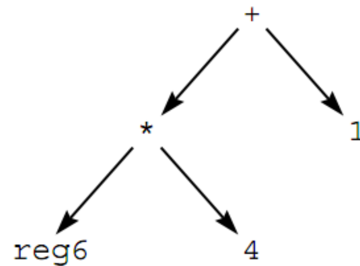
$$(\forall\, x :: \texttt{add64}(x, 0) = x)$$

$$\begin{aligned}(\forall\, a, i, j, x \;\; :: \;& i = j \\ & \vee\ \texttt{select}(\texttt{store}(a, i, x), j) = \texttt{select}(a, j))\end{aligned}$$

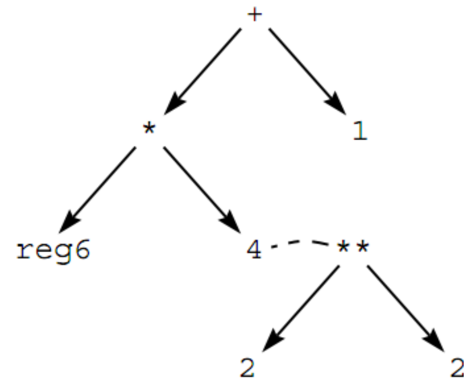
$$(\forall\, w, i :: \texttt{insbl}(w, i) = \texttt{selectb}(w, 0) \texttt{<<}\ 8 * i)$$

E-graph matching: find equiv programs

(a)

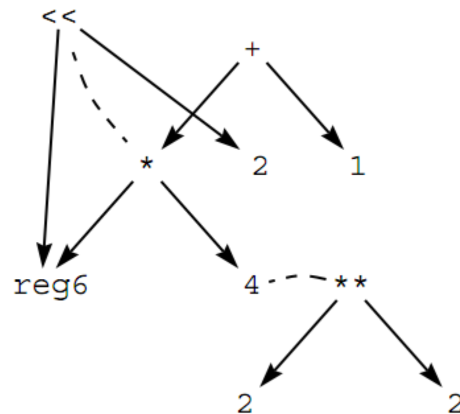


(b)

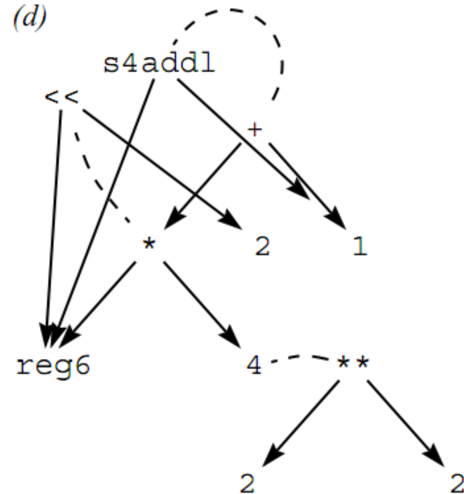


$(\forall k, n :: k * 2^n = k << n)$

(c)



(d)



Prospector

[Mandelin, Bodik, Kimelman 2005]

Software reuse: the reality

Using Eclipse 2.1, parse a Java file into an AST

```
IFile file = …
ICompilationUnit cu = JavaCore.createCompilationUnitFrom(file);
ASTNode node = AST.parseCompilationUnit(cu, false);
```

Productivity < 1 LOC/hour   Why so low?

1. follow expected design? two levels of file handlers
2. class member browsers? two unknown classes used
3. grep for ASTNode? parser returns subclass of ASTNode

Prospector

Problem:

APIs have 100K methods. How to code with the API?

Solution:

Observation 1: many reuse problems can be described with a **have-one-want-one query** *q=(h,w)*, where *h,w* are static types, eg ASTNode.

Observation 2: most queries can be answered with a **jungloid**, a chain of single-parameter "calls". Multi-parameter calls can be decomposed into jungloids.

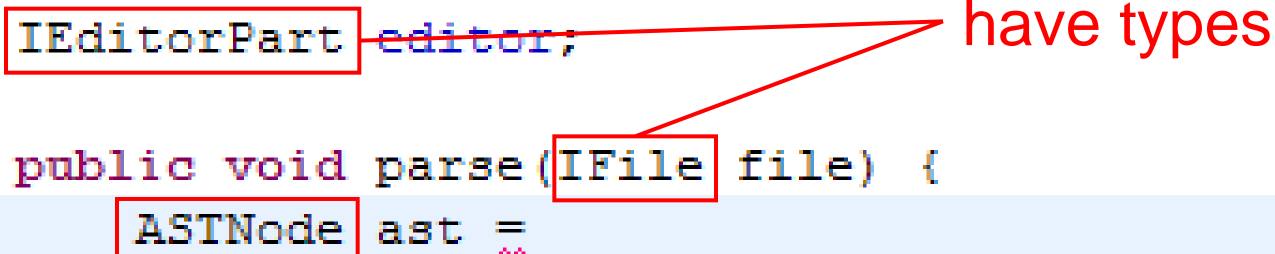
Synthesizer:

Jungloid is a path in a directed graph of types+methods.

Observation 3: shortest path more likely the desired one

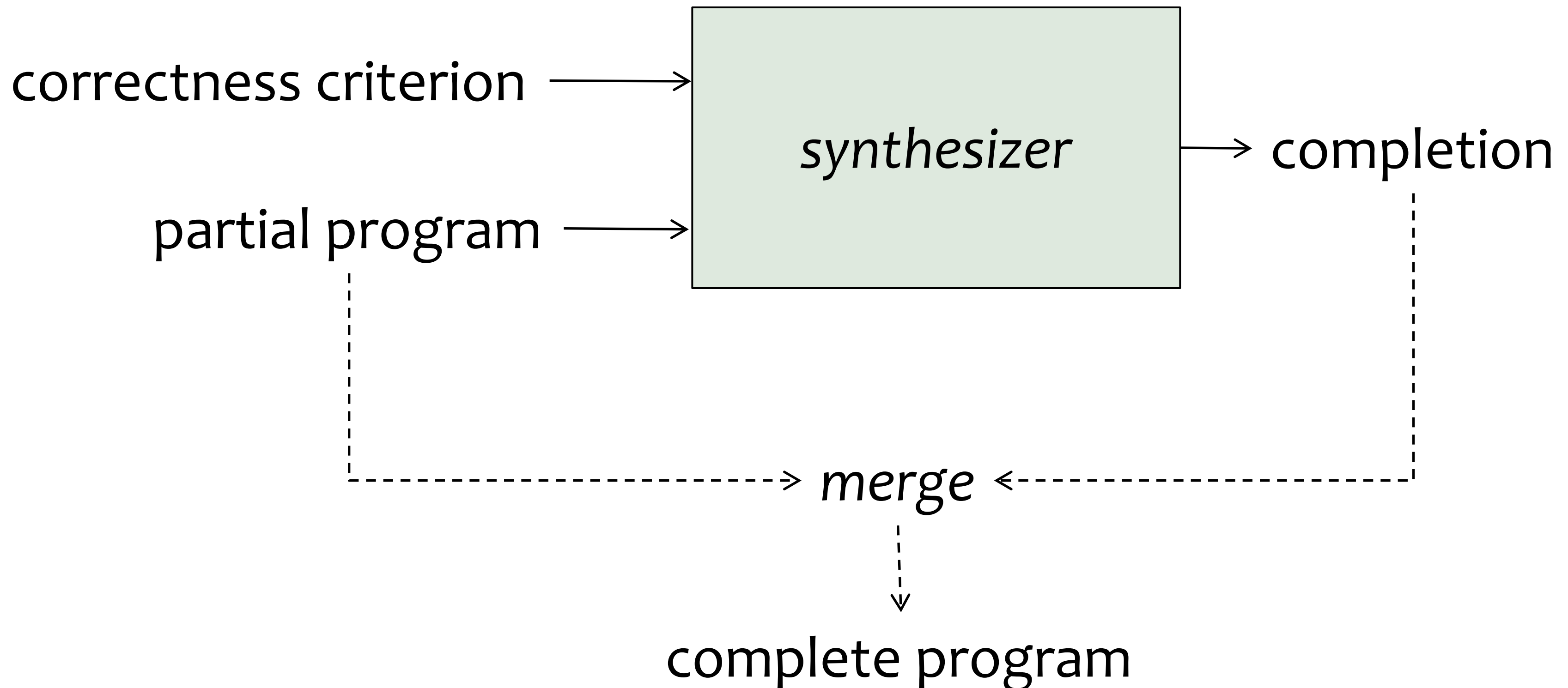
Integrating synthesis with IDEs

- How do we present jungloid synthesis to programmers?
- Integrate with IDE "code completion"

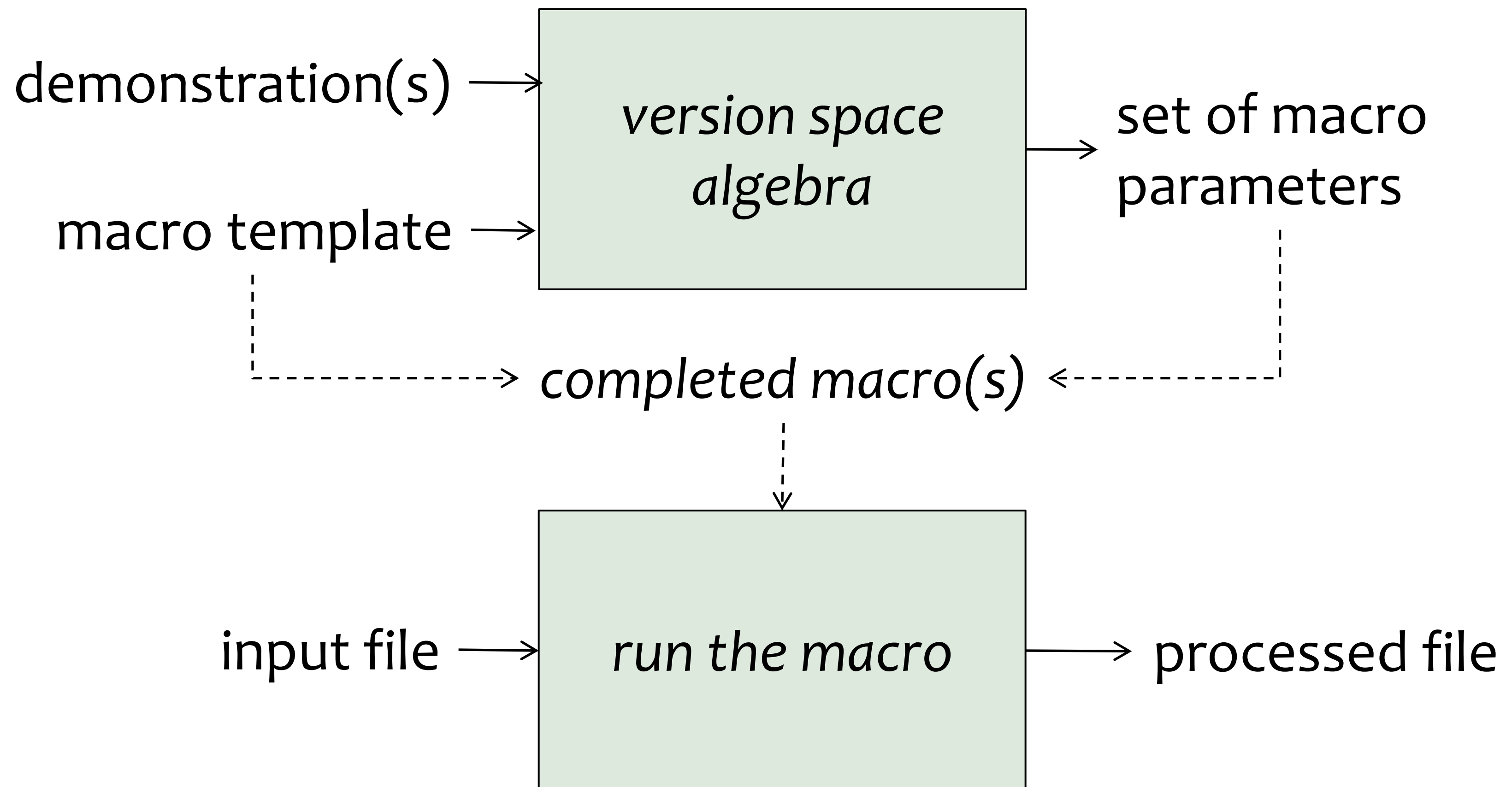


Queries: (IFile, ASTNode)
(IEditorPart, ASTNode)

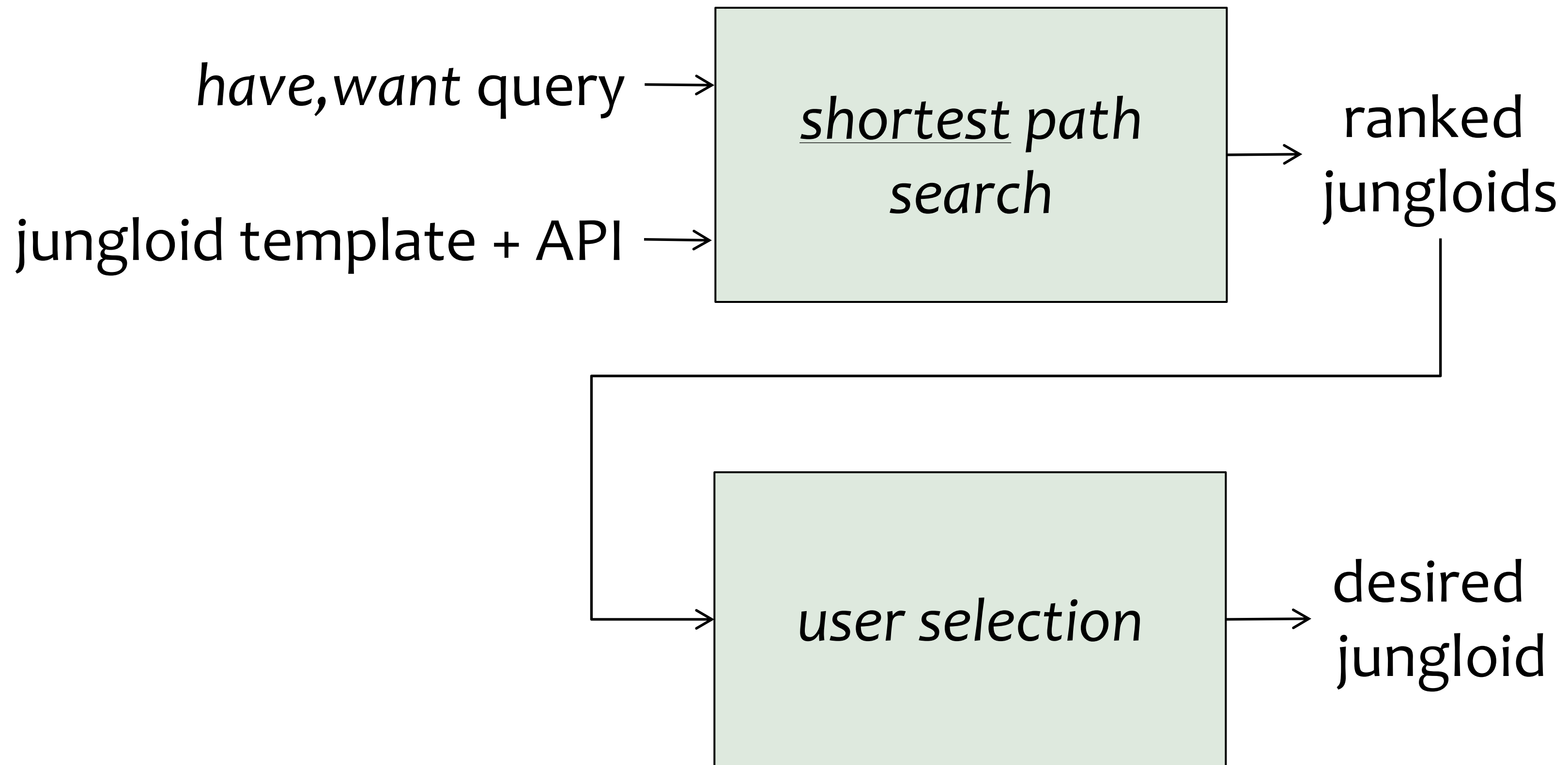
Are these two also about partial programs?



SMARTedit*



Prospector



Turn partial synthesis around?